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TILING OF MODULATOR ARRAYS

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CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims the benefit of U.S. Provisional Application No. 60/456,706, entitled “Modulator tiling arrangement for lithography applications,” filed March 21, 2003 by inventor David T. Amm. The disclosure of U.S. Provisional Application No. 60/456,706 is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field Of The Invention

The present invention relates generally to semiconductor photolithography and, more particularly, to modulator tiling arrangements used in maskless lithography implementations and other applications where optical modulators can be used to create images on optically or thermally sensitive media (including printing applications). Additionally, embodiments of this invention can be applied to applications where arrays of modulators are used to modulate electron beams.

2. Description Of The Background Art

A micro electromechanical system (MEMS) typically includes micromechanical structures or light modulating elements that may be actuated using electrical signals.

The light-modulating elements may comprise, for example, Grating Light Valve™ (GLV®) light modulating elements available from Silicon Light Machines, Sunnyvale, CA (GLV® and Grating Light Valve™ are trademarks of Silicon Light Machines). A light modulator may include an array of moveable structures referred to as "ribbons." Light modulators may be used in various applications, including video, printing, optical switching, and maskless lithography, as just a few general examples.

In a maskless lithography application, a modulator or array of optical (i.e., light) modulators can be moved relative to a surface that an image is to be projected upon. Generally, such an array of optical modulators can create a loose-packed array of exposure zones, or "pixels" on an optically or thermally sensitive material, during a single exposure event. These pixels are typically much smaller than the pitch dimension of the optical modulators. Thus, the array of optical modulators must be scanned in an appropriate manner such that subsequent exposure events can completely fill the media with pixels. This permits high resolution and large pixel density on the optically sensitive media.

Figures 1 and 2 show two conventional modulator arrangements for maskless lithography. Each modulator arrangement includes an array with "n" columns of modulators in the x-direction, and "m" rows of modulators in the y-direction.

Figure 1 shows a conventional modulator arrangement **100** with a scanning direction **106** substantially in the x-direction **102**, but also with a y-direction **104** component such that the scanning direction **106** is at an angle, as indicated in the figure.

In this example, the two-dimensional array includes light modulators **101** with a pitch of "p" and where "n" modulators **101** eventually write "n" pixels **108** within one vertical pitch distance in the scanning process. The written pixel center spacing thus equals (p/n). In this example, the pixel spacing "s" is defined as the distance between the adjacent centers of the printed pixel or exposure location measured substantially perpendicularly to the scanning direction **106** (in this instance, measured in the y-direction **104**). For n = 500 and p = 25 μm (micrometers), then the pixel spacing "s" = p/n = 50 nm (nanometers). If m = 1000, then the total swath width that can be created is: (n)x(m)x(s) = (500)x(1000)x(50nm) = 25 mm (millimeters).

Figure 2 shows a conventional modulator arrangement **200** with a scanning direction **206** substantially in the y-direction **104**, but also with an x-direction **102** component such that the scanning direction **206** is at an angle, as indicated in the figure. In this example, "m" modulators eventually write "m" pixels **208** within one pitch distance in the scanning process. The written pixel center spacing thus equals (p/m). For m=1000 and p = 25 μm, then the pixel spacing "s" = p/m = 25nm. If n = 500, then the total swath width that can be created is: (n)x(m)x(s) = (500)x(1000)x(25nm) = 12.5mm.

SUMMARY

One embodiment of the invention relates to a modulator arrangement configured for maskless lithography or printing applications. The modular arrangement includes at least two array tiles of modulators. Each array tile has a substantially equal modulator

pitch. Each array tile is configured to form a plurality of rows, each row extending in a first direction, and a plurality of columns, each column extending in a second direction, wherein the first direction and the second direction are substantially perpendicular to each other. Two adjacent array tiles are separated by a first displacement in the first direction and a second displacement in the second direction.

Another embodiment relates to a writing points array apparatus configured for maskless lithography or printing applications. The apparatus includes at least two sections, each section having a substantially equal writing point pitch. Each section is configured to form a plurality of rows, each row extending in a first direction, and a plurality of columns, each column extending in a second direction. The first direction and the second direction are substantially perpendicular to each other. Two adjacent sections are separated by a first displacement in the first direction and a second displacement in the second direction.

Another embodiment relates to a method of forming a swath of closely-packed pixels on a surface for a maskless lithography or printing application. An arrangement of modulator array tiles is moved relative to the surface along a scan direction between a first direction and a second direction. If the scan direction is closer to the first direction than the second direction, then a first swath of closely-packed pixels is formed with a swath width in the second direction. If the scan direction is closer to the second direction than the first direction, then a second swath of closely-packed pixels is formed with a swath width in the first direction.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates a conventional modulator arrangement and scanning in substantially an x-direction.

Figure 2 illustrates a conventional modulator arrangement and scanning in substantially a y-direction.

Figure 3a shows an example of a conventional intact modulator arrangement and a scanning direction.

Figure 3b illustrates split and offset array tiles according to a preferred embodiment.

Figure 4 illustrates an example of two array tiles configured according to the preferred embodiment.

Figure 5a illustrates an example four-driver configuration according to an embodiment.

Figure 5b illustrates an example single-driver configuration according to an embodiment.

Figure 5c illustrates an example double-driver configuration according to an embodiment.

Figure 5d illustrates an example configuration with drivers on top and bottom sides according to an embodiment.

Figure 6 illustrates a system application example of tiled modulator arrays and a final focusing array according to an embodiment.

DETAILED DESCRIPTION

The above examples in the background section show the effectiveness of a 500 x 1000 modulator die configuration for maskless lithography applications, as only one example. However, die sizes supporting even larger modulator configurations are difficult to manufacture due to increasing yield loss.

It is therefore desirable to configure a modulator for maskless lithography and other applications using two or more separate modulator arrays. However, multiple die cannot typically be placed side-by-side without a corresponding gap in the array periodicity that can result in associated gaps in the swath coverage. Therefore, what is needed is an arrangement and method whereby a space between multiple modulator arrays can be accommodated to effectively operate in these types of systems.

Described herein are embodiments suitable for maskless lithography and other applications. These embodiments may include light modulators, such as micro-electro-mechanical-systems (MEMS) and devices.

In one embodiment, a modulator arrangement may be configured for a maskless lithography application using at least two arrays of modulators, where each array is a two-dimensional array with substantially equally-spaced modulators. A preferred embodiment includes two 500 x 1000 modulator arrays separated by a displacement in

a first direction and by another displacement in a second direction. In this embodiment, the scanning direction is between the first and second directions so as to form a continuous swath (in other words, a band, scan, or strip of pixels). Additionally, embodiments of this invention can be applied to applications where arrays of optical modulators are used to modulate electron beams which can subsequently expose electron beam sensitive media.

Figure 3a shows a conventional modulator array **300** configured for scanning **306** substantially in the x-direction **302**, similar to Figure 1. By scanning the array at the angle depicted in Figure 3a, a continuous swath of pixels (in other words, a swath of closely-packed pixels) can be formed as shown in Figure 3a by the dotted circles between the solid circles depicting pixels. Control of the pixel placement includes factoring in the scan direction **306** as well as the scanning rate, and timing of the optical modulators **301**, so that light can be modulated and directed to an image surface at the appropriate time to form the continuous swath. For example, for the bottom row of modulators involved in forming the swath as indicated, the rightmost modulator **308** is enabled first, then one modulator over to the left **310** is enabled when it is positioned over the swath area, and so on, until the leftmost modulator **312** is enabled over the designated swath area. In this way, a complete, close-packed, high resolution, two-dimensional image may be formed on an optically sensitive media.

Figure 3a can be contrasted with Figure 3b, which shows a preferred embodiment of the present invention. In Figure 3b, where an array is split into a first array "tile" **352** and a second array "tile" **354**, and where the second array tile **354** is

displaced in the x-direction by "a" pitch distances with respect to the first array tile **352**, then it may be necessary to offset the second array tile **354** in the y-direction by an amount of "b" = (a x s), where "s" is the pixel spacing as discussed above, in order to maintain the continuous (i.e. closely-packed) swath. Here, "s" is equal to the pitch "p" divided by the total number of columns in the plurality (in this instance, two) array tiles. This configuration **350** is best suited for scanning **356** in substantially the x-direction **302**, which is actually some direction between the x-direction **302** and the y-direction **304**, but typically closer to the x-direction **302**. Using this configuration, a swath can be formed using the same scan direction **356** and a similar scan procedure as described above. Note that in this figure, the dotted circles indicate the future or past pixel positions and do not necessarily indicate modulator on/off control positions. While Figure 3b shows an example two tile arrangement, the arrangement may be extended to include three or more tiles with neighboring tiles displaced as shown in the figure.

Figure 4 shows an example two-tile arrangement **400** according to the preferred embodiment. The two-tile arrangement **400** comprises a first tile **406** and a second tile **408**. In this example, each array tile is a two-dimensional array organized as 1000 rows of modulators (m = 1000) and 500 columns of modulators (n = 500). The modulator pitch is represented by "p" and is 25 μm. In this case, each array tile can be a separate semiconductor die so as to maximize the die yield distribution for a given semiconductor process.

A reasonable die spacing (edge to edge) **410** can be about 200 μm. Allowing about 150 μm from each die edge to the modulator column nearest the edge creates a

total displacement of about (a x p) = 200 μm + 2 x 150 μm = 500 μm = 0.5 mm. Thus, the array may be displaced in the x-direction **402**, for example, by a = 20 pitches or cells. In this example, s = 25 nm, so the y-displacement of the die would be set to be about (20 x 25nm) = 0.5 μm. Hence, in order to accommodate such a 0.5 mm gap in the x-direction, the modulator array must be displaced in the y-direction **404** by 0.5 μm, within a precision of approximately 25 nm.

Displacements of this precision can be difficult to achieve. However, in many applications, subsequent focusing arrays (see Figure 6) between the modulator arrays and the optically sensitive material can substantially reduce the required precision. The use of zone plate arrays or refractive microlens arrays reduce the alignment requirement such that the two MEMS die may need to be aligned only within about ±2 microns, which is readily achievable through optical alignment.

While the displacements, as described above, are important in maintaining the ability to form the swaths in similar fashion to a single 1000 x 1000 modulator array, the two arrays can be held separate by any suitable means in this embodiment. Examples of structures that could include at least the two separate array tiles include multi-chip modules or printed circuit board (PCB) structures.

Figures 5a, 5b, and 5c show various driver circuit location examples as coupled to the exemplified modulator array tile **502**. Figure 5a illustrates a first driver configuration **510** where the driver circuits **504** are positioned on three sides of the modulator array tile **502**. The fourth side **512** is left open without any driver circuit **504** since that side **512** will abut a neighboring tile (not shown). Figure 5b illustrates a second driver configuration **520** where a single driver circuit **504** is positioned on one side of the modulator array tile **502**. The opposite side **522** remains open without any driver circuit **504** since that side **522** will abut a neighboring tile (not shown). Similarly, illustrates a third driver configuration **530** where multiple driver circuits **504** are positioned on one side of the modulator array tile **502**. The opposite side **532** remains open without any driver circuit **504** since that side **532** will abut a neighboring tile (not shown).

The driver circuits **504** are used to directly control the modulators. For a light modulator including ribbons, these circuits **504** may control a ribbon deflection, for example. For other types of modulators, these drivers **504** may control a light modulating operation for an individual pixel.

These illustrated driver locations, as well as other driver locations, such as having drivers only on the top and bottom of the array, allow for two or more arrays to be configured with the critical displacements, as described above. In each such case, at least one side of the die must be keep clear, and modulators can be moved relatively close (about 200-400 micrometers) within the edge of the die.

The "half array" could be designed with 1, 2, 3, 4, or more drivers. As another example, four or more such arrays could be constructed, each having driver circuits **504** on only the top and bottom sides of the array tile **502**, as depicted in Figure 5d. This configuration **540** would keep the left **542** and right **544** sides clear so as to implement according to the critical displacements, as described above.

Ultimately, the alignment precision for the use of multiple light modulating die must be met somewhere in the optical system. In many applications, the final component inserted after the modulator array, but before the media to be written upon, is a focusing array, used to create an array of "writing points." These can be optical lens arrays for some applications, but they can be electron beam arrays for media which can be exposed using electron beams. These final arrays can be fabricated as a single unit where the relative alignment of tiled "sections" or "regions" could be fabricated with high precision.

Figure 6 illustrates a system application example of tiled modulator arrays **602**, an optical system **604**, and a final focusing array **606**, according to an embodiment, so as to achieve pixels exposed on the relevant media **608**. The focusing array **606** can include two arrays of lenses arranged substantially as described above for the tiled modulator arrays. Alternatively, electron beam arrays can be used in place of the lens arrays **606**. In either case, the lens or the electron beam arrays can allow for a reduced alignment requirement such that the two neighboring MEMS die may need to be aligned only within about ±2 microns, which is readily achievable through optical alignment. Further, the lens or electron beam arrays can be configured in two or more regions or

sections having substantially the same first and second displacement relationships, as described above for the modulator arrays. Such a system as depicted in Figure 6 may be extended to include three, four, or more modulator array tiles and a corresponding number of lens or electron beam arrays.

Advantages of the embodiments of this invention include significantly lower risk in MEMS (e.g., light modulator) die fabrication, as well as providing an important intermediate solution with flexibility for production development. Accordingly, effective systems can be constructed with half the data rate, reduced PCB complexity, and a smaller optical field. Also, this approach allows for multiple product resolutions with the same MEMS and driver die, such as a 25mm swath at a 50nm step size using a single MEMS die, a 12.5mm swath at a 25nm step size using a single MEMS die, and/or a 25mm swath at a 25nm step size using two MEMS die. Note also that the two MEMS die can remain on the same illumination "periodic lattice", depending upon the y-axis displacement and the illumination type. Accordingly, the alignment correction between die fields may need to be precise only for the final focusing array. That is, a multi-element optical array, or electron-beam array.

While specific embodiments of the present invention have been provided, it is to be understood that these embodiments are for illustration purposes and not limiting. Many additional embodiments will be apparent to persons of ordinary skill in the art reading this disclosure.